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SOLAR AND GEOMAGNETIC EFFECTS ON UPPER ATMOSPHERIC TEMPERATURE

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In recent years a considerable amount of controversy has been generated on the possible sources of heating of the upper atmosphere. Whereas the role played by EUV radiation as an important heat source has received wide acceptance, there appears to be a general lack of unanimity over the possible existence of another heat source of comparable magnitude. Both theoretical arguments and experimental evidences have been presented for and against the existence of a heat source of corpuscular origin and it seems that the subject has generated more heat than light (see for example Paetzold and Zschörner[1], Harris and Priester[2], Jacchia[3,4,5], Nicolet[6], Bartels[7], MacDonald[8], Bourdeau et al[9], Jacchia and Slowey[10] and Jacchia et al[11]). It should be pointed out that the bulk of observational data on atmospheric temperature has come from the satellite drag analysis which essentially gives the atmospheric density at the satellite perigee. The temperature of the isothermal region of the thermosphere (usually referred to as exospheric temperature by Jacchia) is derived by using a suitable model of the atmosphere (Nicolet[12], Jacchia[13]). In order to study the effect of solar EUV and corpuscular radiation, the parameters chosen for comparison are respectively the solar decimeter flux and the daily variations of the geomagnetic activity on the ground. The former is generally believed to be the measure of EUV flux and the latter the measure of the corpuscular activity of the sun. Jacchia[4] and Jacchia and

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Slowey[14], using 10.7 cm flux measurement as an index of EUV radiation and planetary magnetic indices (a_p or K_p) as measure of geomagnetic activity showed that during the period of high sun spot activity, the daily variations of temperature follow the 10.7 cm variations very closely. During the magnetically disturbed period the temperature increases suddenly in direct proportionality to a_p. A direct comparison between EUV flux and temperature was made by Bourdeau et al[9] who showed that even the minor day to day variation in EUV flux was reflected in temperature data giving strong support to the EUV flux as the primary cause of atmospheric heating. Unfortunately, the EUV flux was available only for about a two months period (March 7 to May 15, 1962) and it was difficult to make a general prediction for the entire solar cycle period based on the data of such a short duration. It was shown later by Jacchia and Slowey[10] and Jacchia et al[11] that during the period of low sunspot activity (1963-65), the daily changes in temperature followed the K_p variation and not the 10.7 cm flux variation as was the case during the earlier part of the solar cycle.

The varying effects associated with 10.7 cm flux and K_p on atmospheric temperature during the solar cycle are indicative of the fact that during the period of high sunspot activity the changes in solar EUV radiation are large enough to mask any effect of corpuscular radiation except during severe magnetic disturbances. During the period of low sun spot activity, however, the level of EUV flux remains relatively stationary so that the corpuscular effects on temperature which may be of the same order as during the high solar activity, become noticeable. In fact, a close examination of 10.7 cm flux and temperature data derived from Explorer IX satellite drag analysis (Roemer[15]) supports this view. Both these data

show a marked 27 day variation up to about June 1962. After this period, the 27 day oscillation in both the parameters appears to be damped and temperature appears to follow K_p variation. To establish a possible relationship between temperature and K_p on a day to day basis even during the high sun spot activity period, it is necessary to separate the effects associated with 10.7 cm flux on temperature as far as possible. It is relatively simple to construct a mathematical filter for this purpose in view of the dominant 27 day periodicity present in both 10.7 cm and temperature data. It was found that a filter based on 5 day running means was quite satisfactory partly because of its computational simplicity and partly because of its frequency response for the period of 27 day and above being sufficiently high. A series derived by taking the difference of the original series and the 5 day running mean series would consequently be free from the periods of 27 days and above. A running mean filter has an additional advantage for it does not introduce any phase change between the original and the filtered series (Holloway[16]).

The temperature data used in this analysis are the night-time minimum temperature (T_n) derived from the precisely reduced drag data of Explorer IX satellite (Roemer[15]). This data which approximately covers the period from November 1961 to June 1963 reflects the period of moderate and low solar activity and is particularly suited for studying the day to day variation in view of its good time resolution. Figure (1) shows a daily plot of T_n, 10.7 cm solar flux ($S_{10.7}$) and ΣK_p (the daily sum of planetary geomagnetic indices taken to represent the average magnetic activity of the day) for the period February to May 1962. This data corresponds to a moderately active period (average 10.7 cm flux value = 98). The ΣK_p and $S_{10.7}$ in Figure 1 and the subsequent ones (Figures

2 and 3) have been advanced by one day for better visual comparison with T_n since the initial examination of the data revealed a systematic one day lead of ΣK_p and $S_{10.7}$ with respect to T_n. The significance of this time lag will be discussed later. It is seen from Figure 1 that both the 10.7 cm flux and temperature follow each other quite well but there is no apparent resemblance of either of the two parameters with ΣK_p. The 27 day periodicity is revealed in both the 10.7 cm flux and T_n plots. Figure 2 shows the plot of 5 day running means of 10.7 cm flux ($\overline{S}_{10.7}$), temperature ($\overline{T}_n$), and the daily sum of K_p indices ($\overline{\Sigma K_p}$). It is seen that the smaller fluctuations in all the parameters are considerably smoothed. Both the $\overline{S}_{10.7}$ and $\overline{T}_n$ show clearly the 27 day cycles superimposed on a long term variation. Figure 3 shows the difference ($\Delta S_{10.7}$, ΔT_n and $\Delta\Sigma K_p$) of the original data and the 5 day running means, and essentially contains the high frequency components. The similarity between $\Delta\Sigma K_p$ and ΔT_n is quite striking - a feature which is not obvious from Figure 1. It can be seen that there is no visual correspondence between ΔT_n and $\Delta S_{10.7}$. The significance of the above result is revealed by subjecting the entire data from November 1961 to May 1963 to statistical analysis. The correlation coefficients are computed for the original data ($r_{T_n, S_{10.7}}$, $r_{T_n, \Sigma K_p}$ and $r_{S_{10.7}, \Sigma K_p}$), five days running means ($r_{\overline{T}_n, \overline{S}_{10.7}}$, $r_{\overline{T}_n, \overline{\Sigma K_p}}$ and $r_{\overline{S}_{10.7}, \overline{\Sigma K_p}}$), and five days running mean differences ($r_{\Delta T_n, \Delta S_{10.7}}$, $r_{\Delta T_n, \Delta\Sigma K_p}$, $r_{\Delta S_{10.7}, \Delta\Sigma K_p}$) varying the time difference from -5 to +5 days with an interval of 1 day and are shown in figures 4, 5 and 6 respectively. It is seen from these figures that except for the lack of correlation between $S_{10.7}$ and ΣK_p, the correlation coefficients between the various parameters show significant variations depending on their frequency spectrum.

They all, however, appear to peak at +1 day indicating a possible 1 day time lag of temperature with respect to EUV flux and geomagnetic perturbations. It should be emphasized, however, that no physical significance should be attached to this kind of time delay in view of the fact that both 10.7 cm flux and K_p are averaged over one day period and the maximum resolution of the data is of the order of 1 day. The following table shows the peak values of correlation coefficients between the various parameters.

TABLE 1

ORIGINAL DATA

$r_{T_n, S_{10.7}}$	$r_{T_n, \Sigma K_p}$	$r_{\Sigma K_p, S_{10.7}}$
.65	.32	-.08

5 DAY RUNNING MEANS

$r_{\overline{T}_n, \overline{S}_{10.7}}$	$r_{\overline{T}_n, \overline{\Sigma K_p}}$	$r_{\overline{\Sigma K_p}, \overline{S}_{10.7}}$
.64	.25	-.09

5 DAY RUNNING MEAN DIFFERENCES

$r_{\Delta T_n, \Delta S_{10.7}}$	$r_{\Delta T_n, \Delta \Sigma K_p}$	$r_{\Delta \Sigma K_p, \Delta S_{10.7}}$
.09	.73	.02

The correlation coefficients $r_{T_n, S_{10.7}}$ and $r_{\overline{T}_n, \overline{S}_{10.7}}$ are high and show a broad response with the time difference indicating a high degree of association between the long term variations such as 27 day variations in the two parameters. The correlation coefficient $r_{\Delta T_n, \Delta \Sigma K_p}$ is high and shows a very sharp response indicating that the short term variations in T_n and ΣK_p are highly correlated. The short term correlation between T_n and $S_{10.7}$ ($r_{\Delta T_n, \Delta S_{10.7}}$) is almost negligible.

In conclusion we note that for the period November 1961 through May 1963, the long term variations such as the 27 day variations in the upper atmospheric temperature are correlated with those in 10.7 cm flux. The short term variations in temperature such as the day to day variations, however, are strongly correlated with geomagnetic fluctuations as represented by $\Delta \Sigma K_p$.

We wish to thank Mr. C. J. Wade for programming the numerical computations used in this work.

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FIGURE CAPTIONS

1. Temporal variations of ΣK_p, Temperature T_N, and 10.7 cm solar flux $S_{10.7}$ for the period February, 1962 to May 1962.

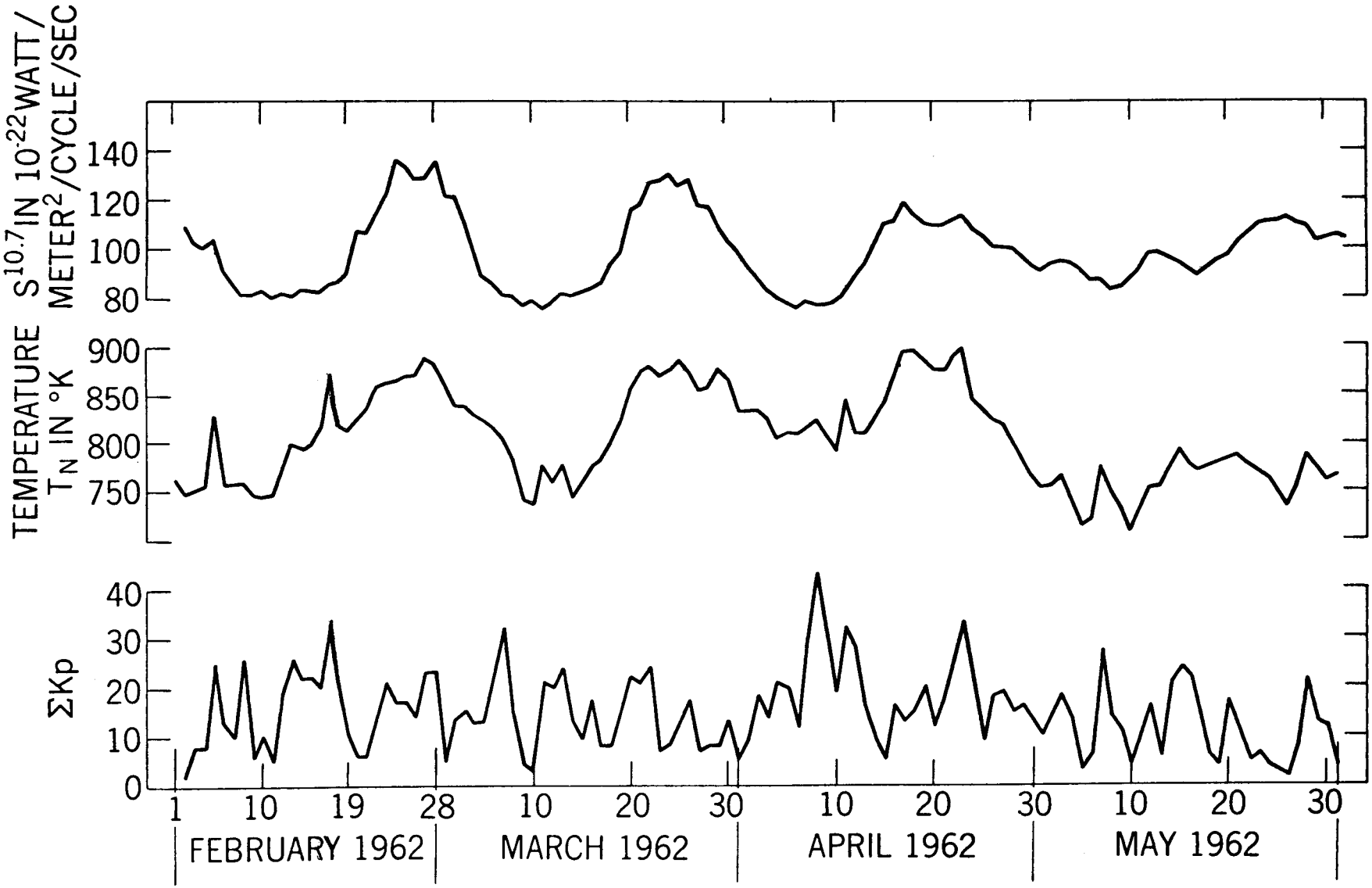
2. Temporal variations of $\overline{\Sigma K_p}$, $\overline{T}_N$ and $\overline{S}_{10.7}$ for the period February 1962 to May 1962.

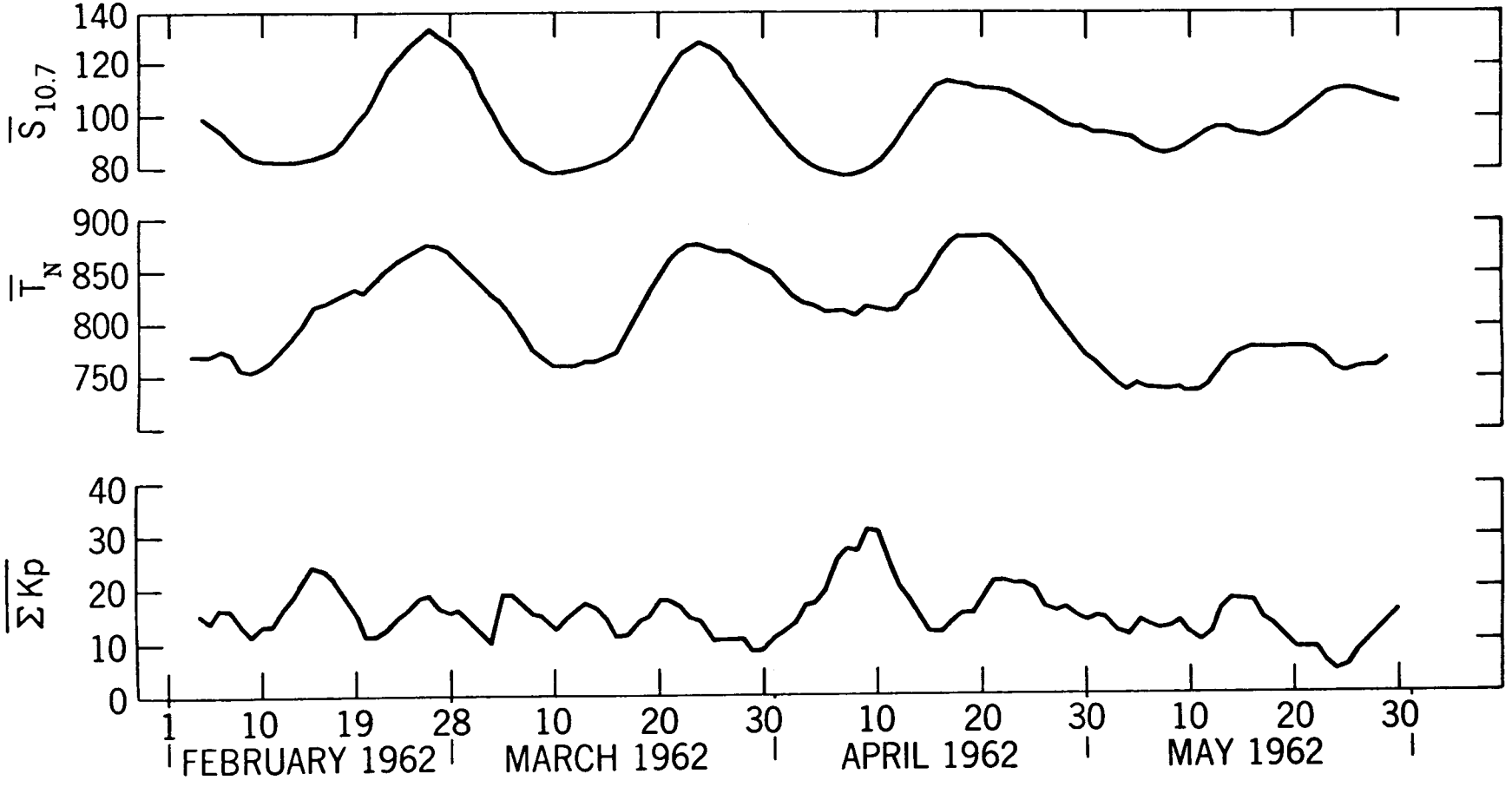
3. Temporal variations of $\Delta\Sigma K_p$, ΔT_N and $\Delta S_{10.7}$ for the period February 1962 to May 1962.

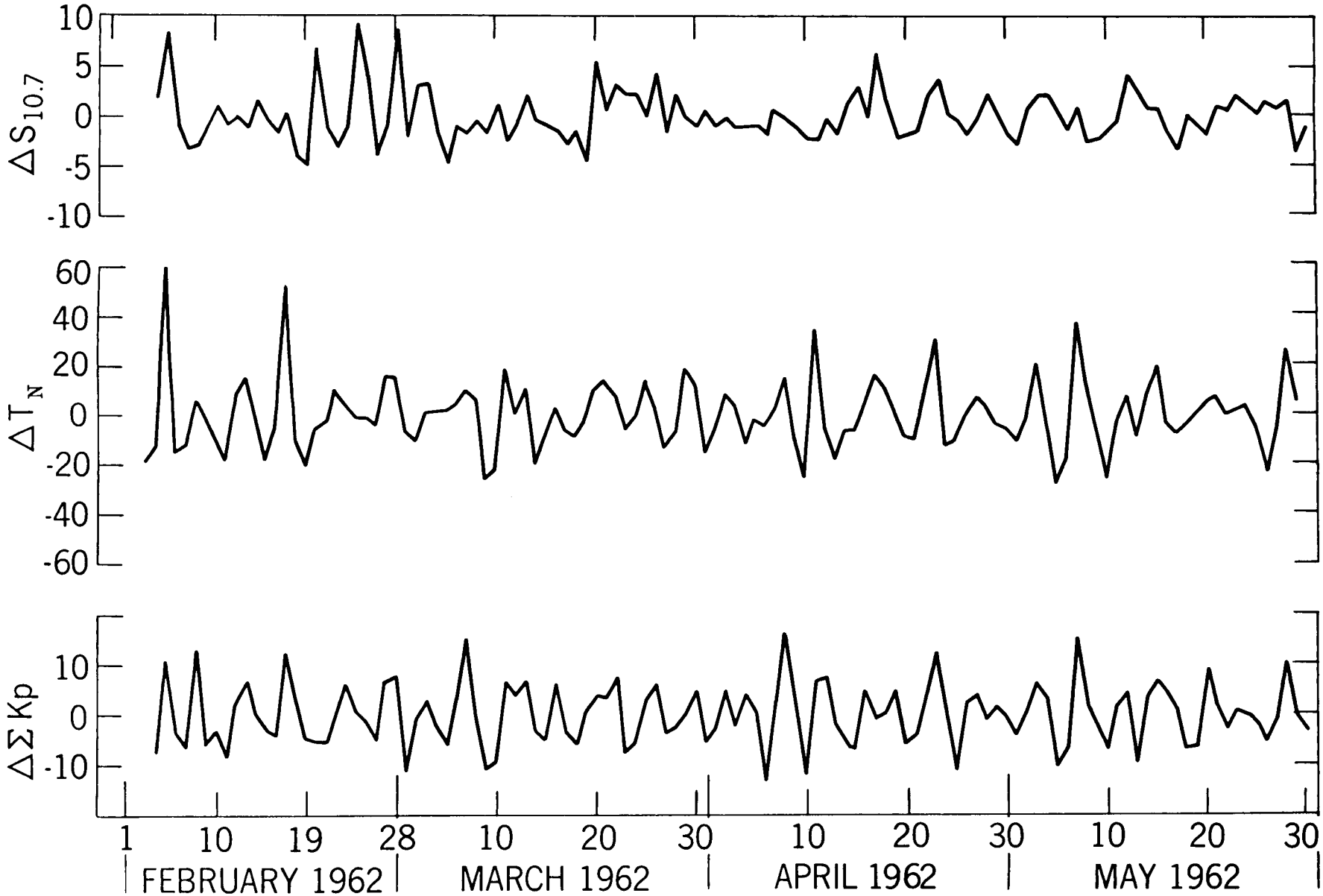
4. Cross correlation with original data.

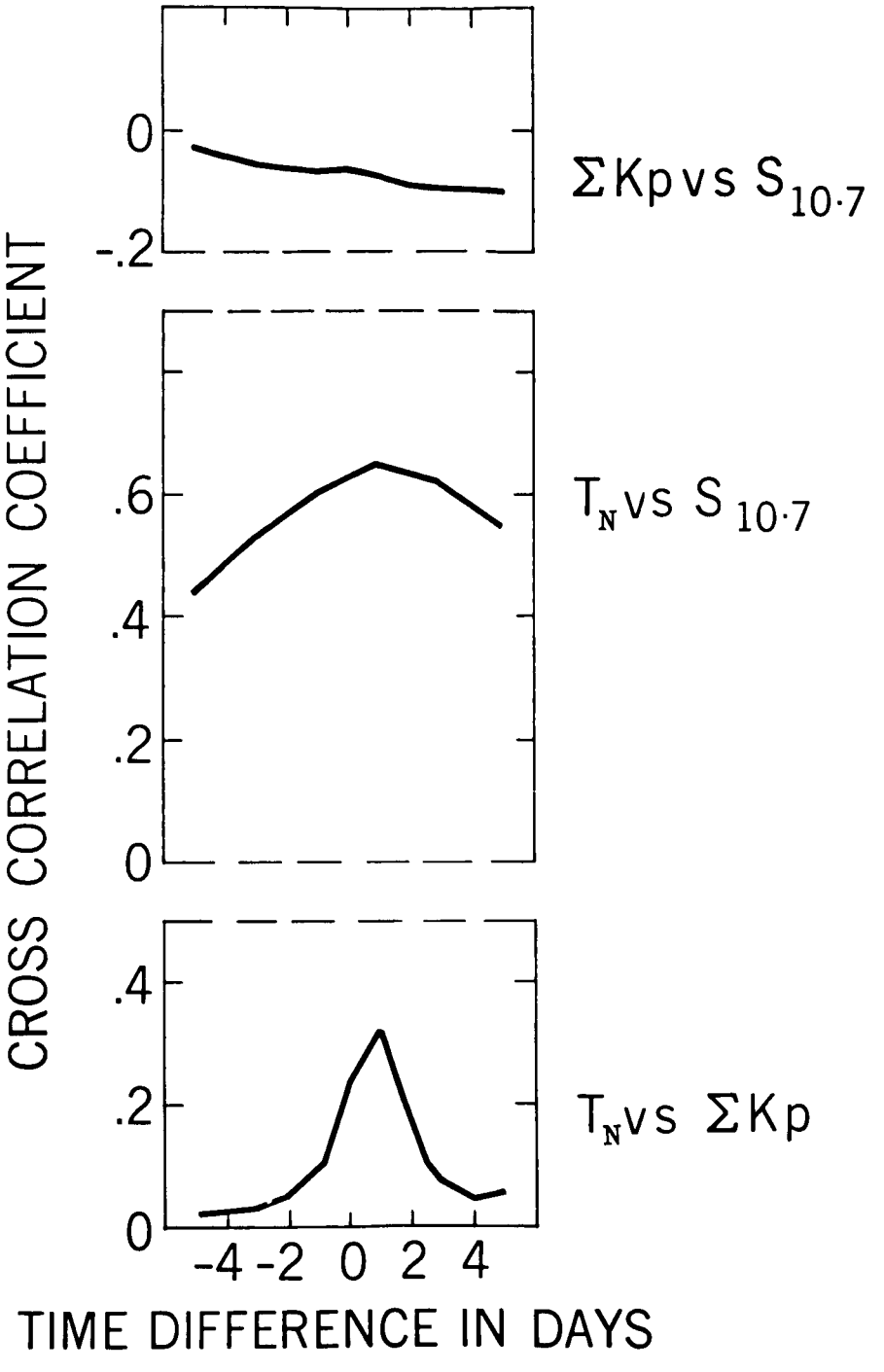
5. Cross correlation with 5 day running means.

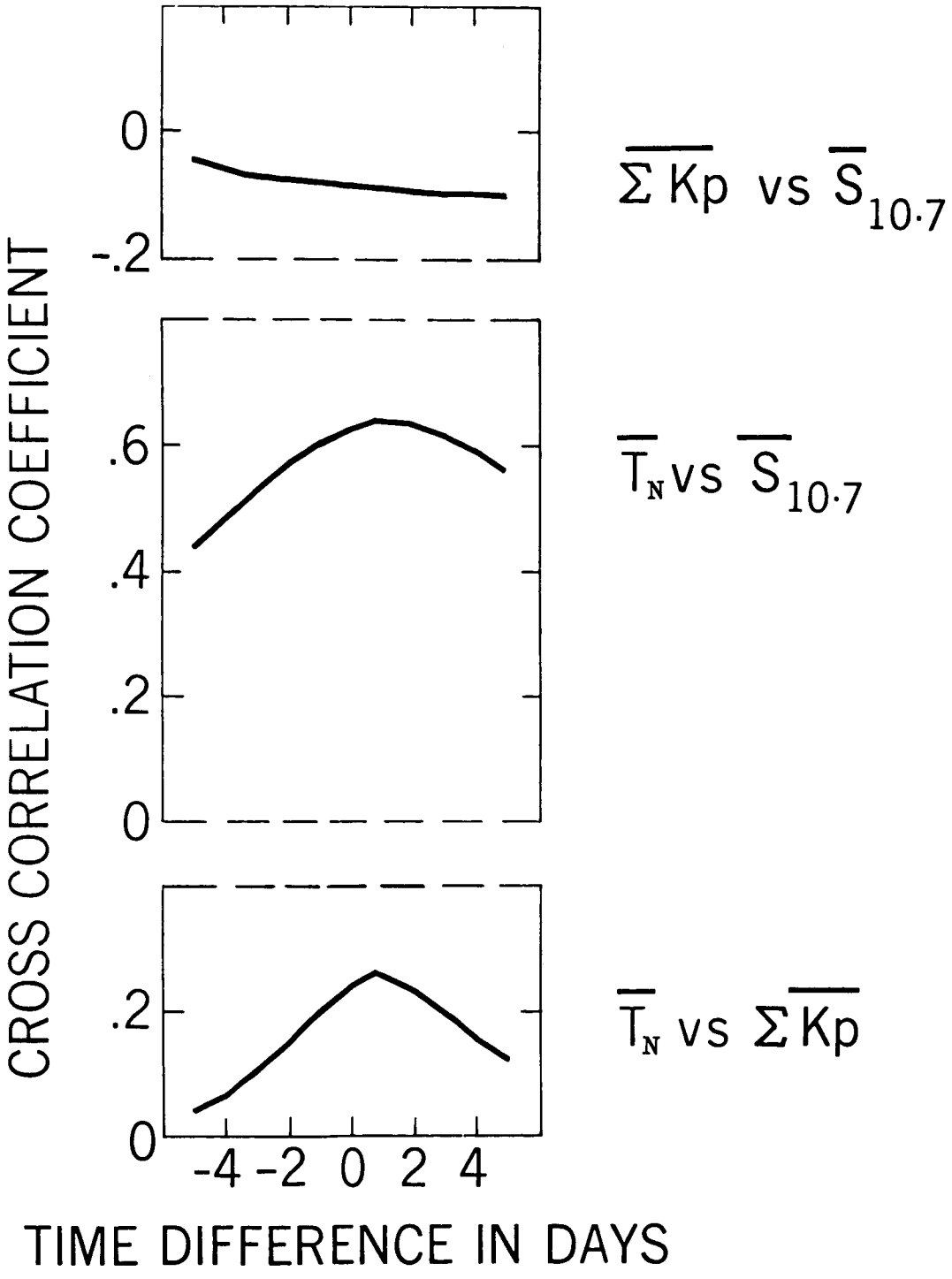
6. Cross correlation with 5 day running mean differences.

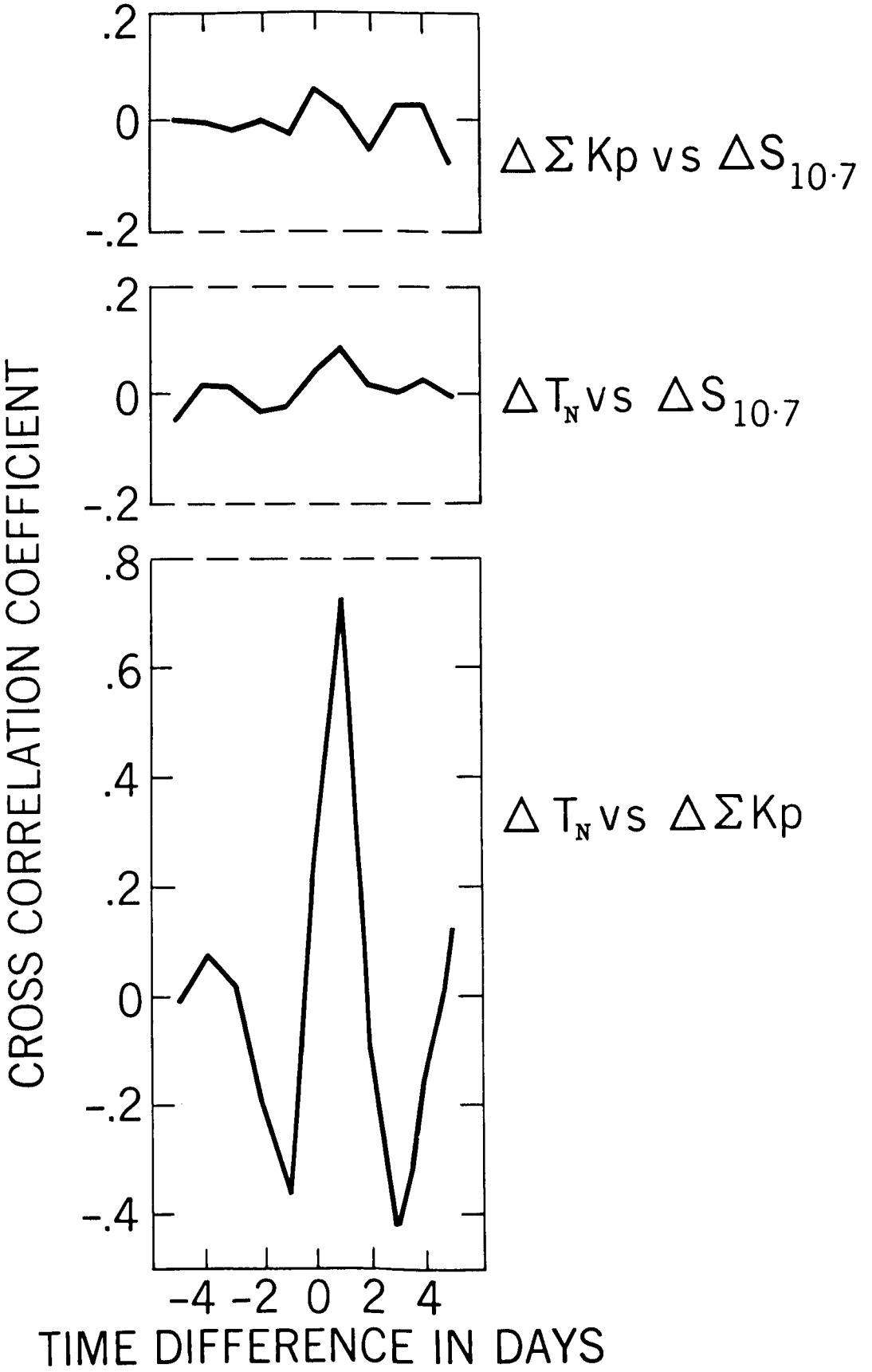

$S^{10.7}$ IN 10^{-22} WATT/ METER^2/CYCLE/SEC
140
120
100
80
TEMPERATURE T_N IN °K
900
850
800
750
ΣKp
40
30
20
10
0
1
10
19
28
10
20
30
10
20
30
10
20
30
FEBRUARY 1962
MARCH 1962
APRIL 1962
MAY 1962


$\overline{S}_{10.7}$
140
120
100
80
$\overline{T}_N$
900
850
800
750
$\overline{\Sigma Kp}$
40
30
20
10
0
1
10
19
28
10
20
30
10
20
30
10
20
30
FEBRUARY 1962
MARCH 1962
APRIL 1962
MAY 1962


10
5
0
-5
-10
$\Delta S_{10.7}$
60
40
20
0
-20
-40
-60
ΔT_N
10
0
-10
$\Delta \Sigma Kp$
1
10
19
28
10
20
30
10
20
30
10
20
30
FEBRUARY 1962
MARCH 1962
APRIL 1962
MAY 1962


0
-.2
ΣKp vs S10.7
.6
.4
.2
0
TN vs S10.7
.4
.2
0
TN vs ΣKp
-4 -2 0 2 4
CROSS CORRELATION COEFFICIENT
TIME DIFFERENCE IN DAYS


0
-.2
$\overline{\Sigma Kp}$ vs $\overline{S}_{10.7}$
.6
.4
.2
0
$\overline{T}_N$ vs $\overline{S}_{10.7}$
.2
0
$\overline{T}_N$ vs $\Sigma\overline{Kp}$
-4 -2 0 2 4
CROSS CORRELATION COEFFICIENT
TIME DIFFERENCE IN DAYS


.2
0
-.2
ΔΣKp vs ΔS10·7
.2
0
-.2
ΔTN vs ΔS10·7
.8
.6
.4
.2
0
-.2
-.4
ΔTN vs ΔΣKp
CROSS CORRELATION COEFFICIENT
-4 -2 0 2 4
TIME DIFFERENCE IN DAYS